



Energy Transition with focus on CO₂ & H₂ Pipelines

COPEX 2022 – Session 1
October 19th 2022

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COPEX 2022 Session 1 – Industrial Challenges Long-Term Mega trends Energy Transition with focus on CO₂ and H₂ Pipelines

Agenda

- CO₂ Pipelines
 - Current CO₂ transport experience
 - Shell participation CCS Projects & FEED Studies
 - Key topics for CO₂ transport
 - Earlier EU CO₂ Network Development Studies
- H₂ Pipelines
 - Role of H₂ in future Energy system
 - Integrated Energy Chemical Parks - Industrial Hubs
 - Current H₂ transport experience
 - Shell H₂ Project involvement and R&D
 - Key topics for H₂ transport
 - Recent EU H₂ Network Development Study

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CO2 Pipelines



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Existing onshore CO2 pipeline systems in USA



139 Number of U.S. CO₂-EOR Projects

- Natural CO₂ Source
- Industrial CO₂ Source
- CO₂ Pipeline
- - CO₂ Proposed Pipeline
- - CO₂-EOR Region

U.S. regions with large-scale CO ₂ pipeline systems currently in operation	Miles of Pipeline
Permian Basin (W. TX, NM, and S. CO)	2,320
Rocky Mountains (N.CO, WY and MT)	810
Gulf Coast (MS, LA, and ETX)	740
Mid-Continent (OK and KS)	480
Other (ND, MI, Canada)	215



- Decades of CO₂-EOR (Enhanced Oil Recovery) industry in the US
- Pipelines are prevalent across the US and Europe
- Highly-skilled pipeline engineers across industry

2020 US PHMSA data for CO2 pipelines:

- 5,150 miles (8,300 km) – all dense phase
- 13% increase over the last decade

Source: U.S. Department of Energy, "Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure," April 2015.

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CO2 Pipeline Transport: Onshore (US EOR) & Offshore



523 km 24" Green Pipeline, Denbury (2010)

808 km 30" Shell Cortez Pipeline (1983)
12 mtpa - 650 MMscfd initial capacity

Now Operated by Kinder Morgan, current Capacity 28 mtpa - 1,500MMscfd



Offshore CO2 Pipeline Transport: a single pipeline to date



153 km 8" Snøwhit pipeline, Equinor/Statoil (2005)
Operational April 2008, Capacity 700 ktpa

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Shell CCS Projects and Strategy Store 25 mtpa CO2 by 2035 & net-zero-emissions by 2050

RENEWABLES AND ENERGY SOLUTIONS
DEVELOPING CCS TO ACCELERATE DECARBONISATION

Shell is working on CCS opportunities that enable:

- Net-zero emissions from own operations
- Low-carbon gas
- Low-carbon hydrogen
- Bio-energy with CCS
- Decarbonising sectors
- Direct air capture

Shell's CCS strategy

- Develop commercial CCS hubs that enable decarbonisation of multiple customers and support Shell's role in the energy transition
- Ambition to store over 25 million tonnes CO₂ per annum by 2035
- Work with governments to help shape their net-zero emission pathways and advocate for CCS through active membership in industrial organisations

Announced CCS projects

- Operational or post FID projects
- Pre-FID projects

- Multiple projects and opportunities in the funnel across different regions with the potential to decarbonise multiple value chains and customers
- Involved in the entire value chain including operating assets, capturing CO₂, building transport and storage infrastructure and developing commercial CCS applications
- Active research and development program advancing technology and supporting project deployment

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Reduce Shell and industry emissions through CCS

- Invest in CCS in North West Europe through a portfolio of projects in the UK, Norway and the Netherlands
- Northern Lights project under construction in Norway. Stores up to 1.5 million tonnes of CO₂ per annum
- Invest in CCS to unlock low-carbon blue hydrogen production for industrial decarbonisation

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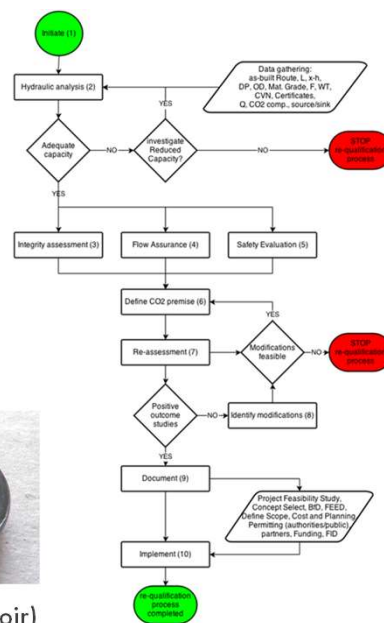
Shell participation CO2 transport Projects & FEED Studies

- **Projects**
 - **Shell Quest CCS Project in Canada**
 - FID taken in 2012, Start CO2 injection 24-08-2015 (5 mtpa stored in nearly 5 years by July 2020)
 - Main line 65 km 12" (150 barg), having a design capacity of 1.2 mtpa
 - **Gorgon LNG (Shell interest 25%)**
 - off the coast of Western Australia, Barrow Island, start injection August 2019 (5 mtpa stored on 19 July 2021)
 - the world's largest CCS Project up to 4.0 mtpa
 - CO2 captured from produced gas, transported by a 7.3 km 12" pipeline
 - **JV Project involvement: Northern Lights (Norway), Porthos & Aramis (Netherlands), NEP & Acorn (UK)**
- **Previous UK FEED studies & various JIP involvement (2010 - 2014/2015)**
 - UK CCS Longannet (FEED completed), no FID taken (cost)
 - Peterhead (FEED completed), no FID taken (cost)
 - Re-use of an existing 20" offshore pipeline (and platform/wells) - now again part of Acorn

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Key topics for CO2 pipelines

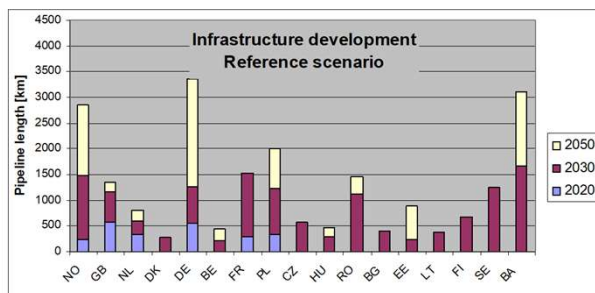
- **Impact of Impurities (CO2 stream composition/specification)**
 - Water solubility, dehydration requirements, corrosion & acids
 - Equation of State, fluid properties, modelling
- **Material selection (Typically Carbon Steel)**
 - Line Pipe toughness (Running Ductile Fracture, RDF)
 - Non-metallics (soft seals)
- **Pipeline Operations & Maintenance**
 - Flow Assurance: Pipeline depressurisation (low Temperature due to phase change)
 - ILL Piggings (velocity, distance, wear, non-metallic materials)
- **Pipeline Requalification (constraints!)**
 - Capacity (design pressure - offshore/onshore), Availability (timing)
 - Line Pipe toughness - RDF, material certificates
 - Integrity status, modifications, valve replacement
 - QRA (Dispersion, Safety) for onshore pipeline, facilities
- **System Integration (capture, compression, pipeline, well/injection, reservoir)**



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CO2 Network development (2011)

- Captured CO2 (mtpa) 2020: 40, 2030: 400, 2050: 1200
- 2050 CO2 network comparable to EU Oil/Products system
- Construction effort ~ 500 - 1,500 km/year
- Key findings consistent with studies JRC (2011), ARUP (2010)



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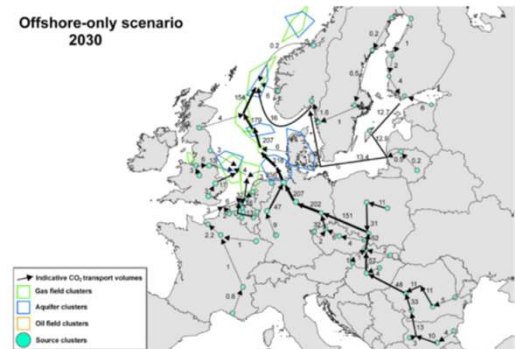
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	Reference scenario	Total trunk line length [km]		EOR scenario
		Offshore-only scenario		
2020	2.300	4.200	5.300	
2030	15.000	20.000	21.000	
2050	22.000	33.000	33.000	

Offshore-only scenario 2030



H2 Pipelines



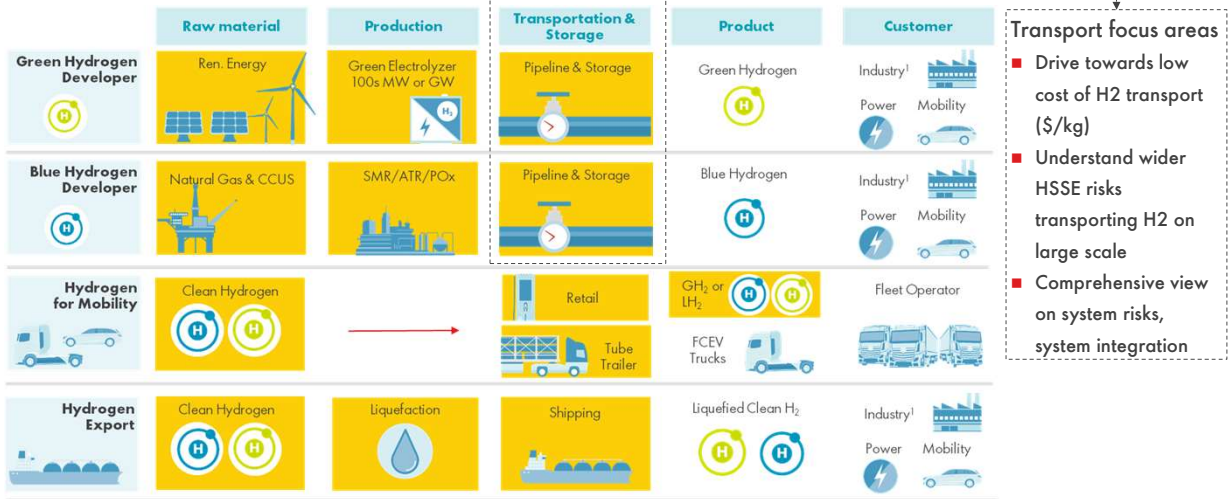
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Overview of Hydrogen in the Future Energy System



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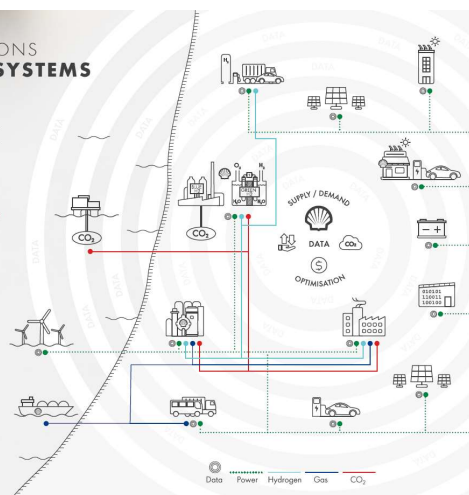
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Integrated Energy & Chemical Parks - Industrial Hubs

RENEWABLES AND ENERGY SOLUTIONS INTEGRATED CLEAN ENERGY SYSTEMS DRIVING HIGHER RETURNS

- The energy system increasingly needs **system-wide optimisation** and the **integration of flexible assets** including the optimisation of customers' own assets
- Shell's capabilities to **match supply and demand** for all our customer use cases and energy types in an **integrated infrastructure** are essential in any future energy system
- Digital platforms provide **new means to meet customer demand** enabling Shell to tap into these growing **value pools**
- These digitally-enabled solutions **go beyond power** and will integrate into **all areas of customer activities** including EV charging, demand management, virtual power plants, LNG, CCS, hydrogen
- Our **competitive edge** to make these integrated systems carbon- and cost-efficient, as well as **trade, optimise** and convert flows of clean power, net-zero natural gas and clean hydrogen, will generate **higher returns for investors**

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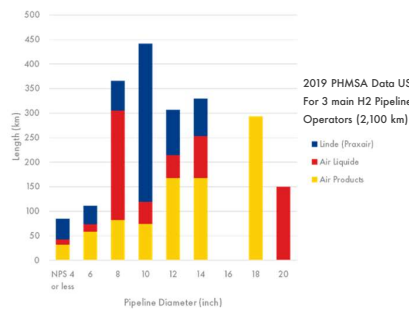
Existing H2 Pipeline networks

Main Industrial Areas of:

- USA Texas/Louisiana
- Germany (Ruhr area), since 1940s
- Rotterdam (NL)/Antwerp (BE)/Northern France

Company (2016)	km
Air Liquide	1,940
Air Products	1,140
Linde (incl. Praxair)	980
Others	480
World Total	4,540

Continent (2016)	km
US	2,610
Europe	1,600
Rest of World	340
World total	4,540



<https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines> (2016)

2020 PHMSA Data US All H2 Pipeline Operators 2,500 km, increase of 14% since 2010 (2,200 km)

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Shell H2 Projects and R&D involvement

Electrolyzer Projects - Operational:

- Germany - Refhyne, 10 MW (July 2021)
- China - Zhangjiakou City, 20 MW (January 2022)
 - Phase 2 plans to scale up to 60 MW in next 2 years



Ongoing Studies:

Refhyne II (Germany)

- 100 MW Electrolyser and SAF project

Green Hydrogen Hub (Netherlands)

- Green Hydrogen plant Tweede Maasvlakte, Port of Rotterdam
- The hydrogen plant will have a capacity of around 200 MW

NorthH2 Feasibility Study (Netherlands)

- Gasunie, Groningen Seaports, Shell, Equinor and RWE
- ambition to grow to about 10 GW around 2040

AquaVentus (Germany) - 90 parties

- ambition to grow to about 10 GW around 2035

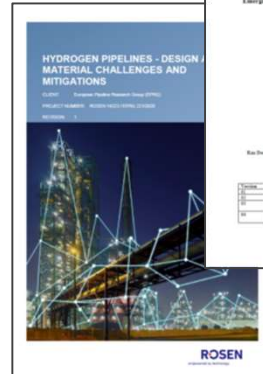
NorthH₂



AquaVentus

Internal & External H2 R&D

- EPRG
- PRCI/EFI



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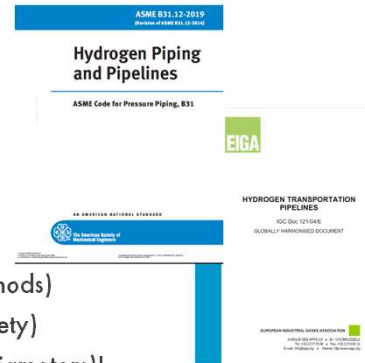
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Key Topics for H2 Transport

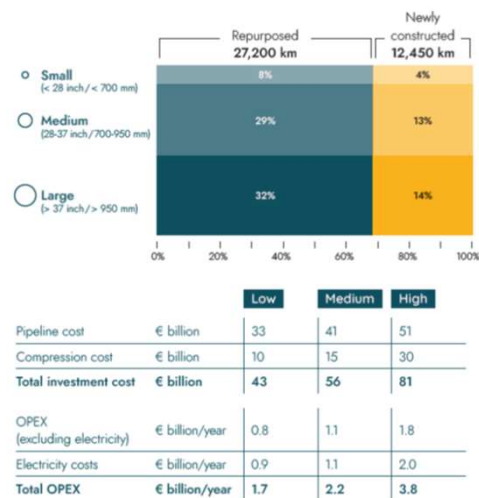
- H2 properties and specifications (purity and contaminants, blending and comparison with methane)
- Design of H2 pipelines (Codes & Standards, EoS, Capacity/Sizing, impact impurities)
- Capacity (Energy) / Buffering H2 pipelines & Storage (Δp – pressure fluctuations, fatigue)
- Material selection (low-grade Carbon Steel, non-metallics - permeation)
 - CS Material Grade & sour service (strength, ductility, toughness)
 - Fracture control (fatigue crack growth): Low Grades & Low Stress level
- Re-use of existing infrastructure, conversion gas pipelines
 - blending H2 with Natural Gas or near pure H2 (timing/availability)
 - integrity status (pipe & welds), fatigue crack growth (defects)
- Construction and commissioning (welding: hardness requirements)
- Operational aspects (compression, inspection, leak detection, repair methods)
- Operational safety aspects of H2 pipelines (permeation, QRA/Public Safety)
- System integration & envisaged scale enlargement (both in Length and Diameters)!



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H2 Network development (European Backbone 2040)

from https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf



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Questions and Answers

Q&A

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